



## **JOINT STATEMENT OF POSITION**

For over a year, representatives of the National ITFS Association, Inc. ("NIA") and the Wireless Cable Association International, Inc. ("WCA") have been meeting in an effort to come to agreement on issues of mutual interest deriving from the emerging use of digital technology on Multipoint Distribution Service ("MDS") and Instructional Television Fixed Service ("ITFS") channels. The underlying goal of these negotiations has been to craft a regulatory environment that assures that the educational community reasonably shares in the benefits that digital technology will permit, while permitting the wireless cable industry to become a viable competitive force in the marketplace (which benefits both the wireless cable industry and the ITFS community). After significant compromise by each side, NIA and WCA have come to agreement that the public interest will best be served by incorporation of the following concepts into the rules and policies of the Federal Communications Commission. Moreover, NIA and WCA have agreed to create a standing working group to address current and future issues of concern. Because the following concepts reflect a series of compromises between the parties on matters that are inextricably intertwined, NIA and WCA jointly urge the Commission to adopt them en toto without change.

- I. In order to assure the substantial educational use of the ITFS spectrum, each ITFS licensee shall, at a minimum, have the right to use 25% of capacity of its channels. In any digitized system the ITFS licensee shall be required to deliver no less instructional material than is currently required for analog ITFS systems under Section 74.931(e) of the Commission's Rules.
- II. In order to assure the immediate availability of capacity for immediate ITFS usage, each ITFS licensee leasing capacity for digital usage shall refrain from leasing an amount equal to no less than 5% of the capacity of its channels.
- III. Each ITFS licensee that leases excess capacity for digital services must maintain the ability to recapture for the transmission of ITFS programming at least an additional 20 % of the capacity of the channels it leases. The lowest permissible annual rate of recapture shall be 5% of the capacity of its ITFS channels, with a maximum one year advance notice per instance of recapture. The right to recapture may be deferred during the first five years of any excess capacity lease agreement upon agreement of the parties. The parties may agree to an economic adjustment of the ITFS licensee's consideration under the agreement upon recapture, provided that any economic detriment shall not be disproportionate to the amount of capacity recaptured and shall


not include any "Baseline Consideration." "Baseline Consideration" shall be defined to include: (1) any transmitters, transmit antenna, combiners and waveguide necessary to operate the station ("Station Equipment"), (2) any transmit site lease costs necessary to house the Station Equipment; and (3) the utility and maintenance costs necessary to maintain and operate the Station Equipment.

- IV. All ITFS licensees should be permitted to "channel load" any or all of their capacity onto any ITFS channel within the same multi-licensee system. Such "channel loading" shall not be considered negatively at the time the ITFS licensee seeks renewal of its authorization.
- V. Any ITFS licensee should be permitted to "swap" channels with any other ITFS or MDS licensee in the 2.5 GHz band operating in the same geographic area. Particularly in order to promote the introduction of advanced technologies, applications for Commission approval of such swaps should be given expedited consideration by the Commission.
- VI. In recognition of the difficulties that may be faced in converting spectrum used for return paths to downstream uses, each ITFS licensee that leases channels to be employed for return paths shall be required to maintain at least 25% of its licensed channels to be used for downstream transmissions during the term of the lease and following termination of its leasing arrangement.
- VII. ITFS licensees should be permitted to enter into excess capacity leases of up to fifteen years duration, provided that any lease extending beyond the term of a licensee's authorization provides for termination of the lease in the event the Commission denies an application for renewal.
- VIII. Excess capacity lease agreements that provide for digital usage and were entered into prior to the release of an order adopting these concepts shall be grandfathered for their duration.
- IX. ITFS licensees should have opportunities equal to those afforded MDS licensees to implement advanced technologies utilizing their spectrum.
- X. Authorizations for return paths and boosters on ITFS channels should be issued in the name of the ITFS licensee of that channel.

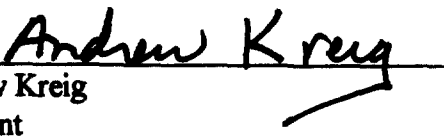
XI. The Commission should adopt rules providing for the expedited processing and granting of applications to introduce advanced technologies on MDS and ITFS channels, provided that the rules assure incumbents protection against any impermissible harmful electrical interference that results upon the initiation of service. In the application of expedited processing and grant procedures for two-way systems, ITFS licensees must be protected from impermissible interference caused by two-way or booster operations, whether or not an ITFS licensee has petitioned to deny an application and/or whether or not the licensee is a participant in an excess capacity agreement.

XII. All excess capacity leases shall provide that the ITFS licensee shall have the right to use any Internet services offered over the system at no greater than the lowest prevailing commercial rate and shall have reasonable access, at rates to be negotiated between the parties, to other services offered over the system (such as addressability and two-way capability).

NATIONAL ITFS ASSOCIATION, INC.

By:   
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# **Power Limitations for Response Station Transmitters: An Analysis**

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### **Commission proposal**

In its Notice of Proposed Rulemaking on MDS and ITFS Fixed Two-Way Transmissions (FCC 97-360), the Commission has proposed to place limitations on the power that can be used at response stations under the blanket authorization of associated response station hubs. Use of higher powers by individual response stations would require that they be separately analyzed for interference potential and licensed on a site-specific basis.

The limiting value proposed by the Commission is +18 dBW. While no rationale for the selection of this particular value is given, it seems to have come from the limit currently applied to booster stations. As will be shown, such a value will place an undue constraint on the level of service that can be offered in a timely fashion.

### **Requirements for service**

In order to evaluate the appropriateness of a particular power limitation, it is necessary first to examine the requirements for the service and to understand its application. Included in such a study must be all the other factors that will determine the success or failure of each installation. In the case of response stations, this will include the matter of frequency reuse, the system architecture, the required information rate, the bandwidth, the modulation type and its density, the distance to be covered, the reliability required, the fade margin needed to achieve the required reliability, and the power to be used.

#### ***Frequency reuse***

In establishing two-way services on wireless cable frequencies, a fundamental motivation of system operators will be to obtain maximum efficiency in use of the spectrum. If the service is successful, there will be more users of the service than can be given their own channels on which to communicate. This will require sharing of the spectrum by several users at one time – a condition known as frequency reuse. Frequency reuse requires that one or more techniques be applied to the system architecture and detailed system design to permit those multiple users to transmit simultaneously without interfering with another.

#### ***System architectures***

There are two fundamental techniques that can be applied to systems to permit frequency reuse. They result in different system architectures if used alone and can be used in combination as well. The techniques, in turn, are aided or enabled by two additional techniques that are applied in tandem with the first pair. The primary techniques are cellularization and sectorization; the secondary techniques are frequency alternation and polarization alternation. The two primary techniques also can be used in combination with one another to further increase the possibility of frequency reuse.

Cellularization involves the division of the service territory into a number of areas covered by different hub sites. Its use can shorten the distance between response stations and their associated hubs, thereby reducing the transmitter power required and increasing path reliability for any given power level. Both frequency and polarization alternation can be applied with cellularization to aid in reduction of internal interference between cells within a system. Cellularization is a relatively expensive way of accomplishing frequency reuse and consequently is likely to be most useful in areas with high population densities and concomitant very high system utilization.

Sectorization entails the division of a response service area into a number of pie-wedge shaped sectors in which separate communications channels can be established on the same frequencies. Because the hub antenna sectors must overlap in order to avoid gaps in coverage, additional means must be provided to separate the signals from stations in the overlap regions into one sector or another. This can be done using alternating frequencies or polarizations in adjoining sectors. Sectorization without cellularization allows greater distances to be covered from a single response station hub but at the expense of requiring higher

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transmitter power and potentially resulting in reduced path reliability. Sectorization by itself permits relatively large areas to be covered at relatively much lower costs than required for cellularization. This combination of characteristics makes it especially appropriate for serving the lower population densities spread over wide areas found in rural regions.

### ***Information rate***

In determining the various performance attributes required of the return path portion of a two-way system, the fundamental feature that must be accommodated and that governs the overall system capacity is the information rate of the path – i.e., the basic rate of data transfer. It sets not only the rate at which data can be sent from a user to the hub but also the number of users that can be accommodated at one time and, because of its use to provide the acknowledgments needed for connection-based data transfer, the rate at which downstream data can be transferred to a user. The requirements for information rate will be determined by the applications to be supported and the number of system users to be supported. The values that it can take depend heavily on the type and density of modulation and the bandwidth utilized.

### ***Modulation type & density***

Several different types of modulation are candidates for return path transmissions, although not all of them have yet been approved for use in the MMDS and ITFS services. These modulation types include BPSK, QPSK, QAM, VSB, OFDM, and CDMA, among others. The type of modulation chosen and the density of its symbol constellation determine the received carrier-to-noise ratio (C/N) required for proper data recovery and consequently the transmitted power required to produce that power level at the receiver (after accounting for other factors such as frequency, distance, and antenna gains). The choice of modulation type will depend upon the combination of the cost of the technology and the requirements of the application. Consumer installations, for example, will require low cost technology, perhaps at the expense of providing a relatively low bit rate. Commercial installations are likely to need higher bit bandwidths but can afford the increased transmitted power and cost of the modulation technology needed to achieve the greater throughput. There is thus a trade-off between modulation complexity (density) and the RF power needed to carry it, which trade-off will be adjusted according to the needs of the particular application.

### ***Bandwidth***

Once the type of modulation and its density are chosen, the bandwidth allocated to the signals will determine the actual information rate that can be transported. The bandwidth needed is a combination of that necessary to carry the information and the roll-off regions necessary to accommodate the selectivity skirts of the filters used to control the emissions of the signal. In establishing the bandwidths of signals used for response station transmissions, it is important to keep in mind the need to achieve relatively flat power spectral density across the 6 MHz channels that are licensed and on the basis of which interference is calculated.

### ***Distance***

The power that will be required to deliver a signal of any given type and density of modulation will depend, along with other factors, on the distance to be covered. While the necessary power can be reduced by moving hubs closer to response stations through cellularization, as discussed previously, many systems will not be able to afford cellularization, thereby mandating that response signals must reach all the way back to a central transmitter site. Thus sufficient power must be available, particularly in rural situations likely to use a single, probably sectorized hub, to cover the 35 miles from a protected service area (PSA) boundary back to a central hub collocated with the downstream transmitter.

In figuring the power required to cover a given distance, factors such as the free space path loss, any excess path loss used, and the fade margin required must be related to the distance. Free space path loss is a well known parameter. Excess path loss can be determined by a number of algorithms when specific paths from transmitter-to-receiver are analyzed using path profiling techniques. In the general case of wide area coverage such as MMDS and ITFS, it is more appropriate to use experience in the field to establish a

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suitable value. Experience with MMDS and ITFS installations points to the use of 10 dB excess path loss up to a distance of 10 miles, a value in dB equaling the distance from 10 to 20 miles, and a value of 20 dB at distances over 20 miles.

The excess path loss included in this context is based on the experience of a large number of wireless cable operators in the eastern half of the United States, where there is heavy foliage in many markets and there are no tall mountains on which to put transmitters (or response station hubs). If only the western half of the country were considered, lower values might be used over at least part of the range of distances treated. Similarly, if only tall buildings or tall masts were used for the subscriber ends of the paths, the excess path loss probably could be reduced. Since very many systems do exist in the east and since it is general practice, at least with residential installations, to mount antennas as low and as concealed as possible, the higher excess path loss that is realistic for these situations must be used in evaluating the power levels that will be required in order to provide reliable service. Hence the values given above are used in the analysis that follows. This leads to a rather pessimistic view of the power required in some cases but is useful for evaluating the power that will be needed in a great many instances.

### Reliability

When establishing a data communications system, another factor that must be considered is the reliability expected to be delivered. Microwave paths experience signal fades, and sufficient fade margin must be provided so that fades below the reception threshold for the modulation type and density used do not occur for longer periods over time than the designed value. Reliability is normally expressed in terms of a percentage, with common values being 99%, 99.9%, 99.99%, and 99.999%. These represent annual outages of 88 hours, 8.8 hours, 53 minutes, and 5.3 minutes, respectively. A typical selection for the types of service contemplated for MMDS and ITFS applications is 99.99% availability, corresponding to 0.01% outage time, or 53 minutes per year.

### Fade margin

In order to achieve the target reliability for a signal path, the fact that fading occurs must be taken into account. Since, over a given distance, the length of fades varies inversely with their depth, there is a direct relationship between the power transmitted and reliability of the channel. The path consequently must be designed with sufficient transmitted power to overcome all fades not occurring more extensively than those associated with the expected outage period. The additional power allocated to overcoming fades is the fade margin, and it is directly related to the distance traversed by the signal. Thus longer paths require larger fade margins to achieve a given level of reliability.

The reliability resulting from any combination of frequency, distance, and fade margin when propagated over terrain having certain generalized characteristics is given by Barnett<sup>1</sup> and Vigants<sup>2</sup> as:

$$U_{ndp} = a \cdot b \cdot 2.5 \cdot 10^6 \cdot f \cdot D^3 \cdot 10^{\frac{F}{10}}$$

where:

$U_{ndp}$  = Unavailability Probability in Non-Diversity situations (= 1-Availability)

F = Fade Margin (dB)

f = Frequency (GHz)

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<sup>1</sup> W.T. Barnett, "Multipath Propagation at 4, 6, and 11 GHz," Bell System Technical Journal, Vol.51, No. 2, February, 1972, pp. 311-361.

<sup>2</sup> A. Vigants, "Space Diversity Engineering," Bell System Technical Journal, Vol. 54, No. 1, January, 1975, pp. 103-142.

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$D$  = Distance (miles)

$a = 4$  for very smooth terrain including overwater, 1 for average terrain with some roughness, 1/4 for mountainous, very rough, or very dry terrain

$b = 1/2$  for hot & humid areas, 1/4 for normal interior temperate or northern, 1/8 = mountainous or very dry

Solving this equation for fade margin and using fixed values of 99, 99.9, 99.99, and 99.999 per cent availability, frequency of 2.686 GHz, and  $a = 1$ ,  $b = 1/4$ , yields the relationships between fade margin and

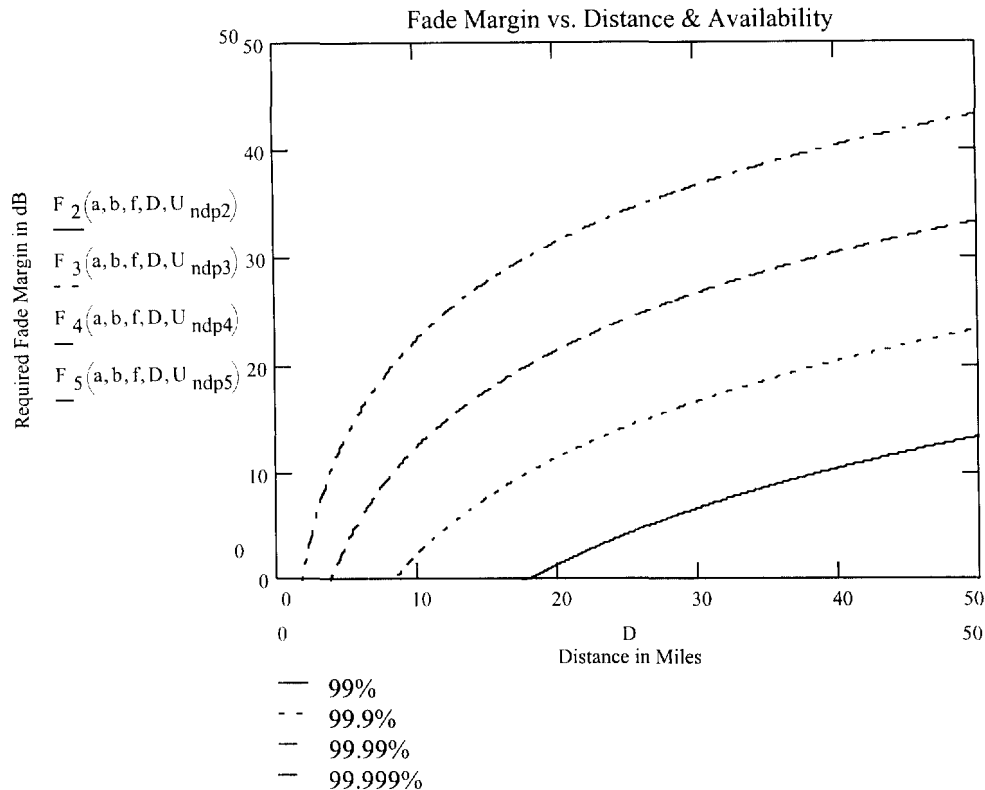


Figure 1 — Fade margin vs. distance & availability

distance given in Figure 1.<sup>3</sup> (Note that the values of fade margin are clipped at zero so as not to allow negative values.)

### Reciprocity

If true two-way service is to be achieved, then the two paths providing the connection (to and from the subscriber) must be approximately equal in their coverage and reliability. This will allow the provision of return (upstream) signals from any location at which the downstream signals can be received. Reciprocity of this kind requires that essentially the same fade margin must exist in both directions. The actual power necessary to achieve such reciprocity depends on the complexity and bandwidth of the signals used in each direction and the resulting threshold signal level. If identical signal characteristics are used in both directions, then equal power, as measured in terms of equivalent isotropic radiated power (EIRP), must be

<sup>3</sup> See also Attachment 1, "Analysis of Response Station Range vs. Bandwidth & Power," prepared by S. Merrill Weiss, Merrill Weiss Group, which gives the development of the charts used in this discussion.

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transmitted both ways in order to achieve reciprocity. To the extent that signal characteristics differ, the power levels used in each direction can also be different.

### Power

The power required to be transmitted in a given instance is the product of many other factors. The modulation type used and the density of its constellation will determine the threshold carrier-to-noise ratio required to receive the signals. System designs can trade off the power required at the receiver for the chosen modulation type and density (as determined by the required carrier-to-noise ratio plus the fade margin) against the bandwidth of the signal and its resulting data capacity. The reliability of the signal, as expressed by its availability percentage, will be a function of the fade margin relative to the length of the path, as discussed above. When all of these factors are taken into account, the desired system reliability and capacity can be obtained by making appropriate trade-offs between other signal characteristics.

If, for example, relatively low bit rates are needed and the power level must be kept low, a low modulation density can be used, but bandwidth efficiency will also be low. On the other hand, if high bandwidth efficiency is desired and a high throughput is needed, a high modulation density can be used together with a wide bandwidth, but relatively high power will be required. If a high reliability is also necessary and a long path is involved, then a high fade margin must be provided, and very high transmitted power must be used. The signal characteristics thus are selected to fit the needs of the particular application.

### EIRP limitation inadequate

In the FCC's NPRM, a limitation of +18 dBW (+48 dBm) EIRP is proposed. As shown in the following series of tables, this implies limitations in the distance over which service can be provided that depend on the reliability required, the type of modulation to be used, and the bandwidth to be transmitted. Examples are given in separate table sections for subchannels of 100 kHz, 600 kHz, 1 MHz, and 6 MHz, representing a total of 60, 10, 6, and 1 subchannels per 6 MHz channel assignment, respectively. The approximate data capacity of each of these subchannel bandwidths using four popular forms of modulation likely to see service in response station applications is given in Table 1. In this tabulation, excess bandwidth to accommodate filter roll-off is assumed to be 30 percent of the overall channel width, resulting in 70 percent channel efficiency. This is a reasonable value for high volume, relatively low cost applications such as subscriber installations in which cost is a significant factor.

**Table 1 — Bit Rates Achievable with 4 Subchannel Bandwidths  
& 4 Modulation Types at 70 % Channel Efficiency**

	BPSK	QPSK	16-QAM	64-QAM
100 kHz	70 kb/s	140 kb/s	280 kb/s	420 kb/s
600 kHz	420 kb/s	840 kb/s	1.68 Mb/s	2.52 Mb/s
1 MHz	700 kb/s	1.4 Mb/s	2.8 Mb/s	4.2 Mb/s
6 MHz	4.2 Mb/s	8.4 Mb/s	16.8 Mb/s	25.2 Mb/s

## Power Limitations for Response Station Transmitters: An Analysis

When all of the characteristics described so far, i.e., modulation type and density, required carrier-to-noise ratio, subchannel bandwidth, distance, reliability, fade margin, free space and excess path losses, and power are combined, the result can be shown as a series of curves relating some of these parameters to others. Figure 2 shows the relationships between distance and the bandwidth that can be transported with a fixed power level of +18 dBW and a fixed availability percentage of 99.99 percent with the four forms and densities of modulation given in Table 1 and accounting for the several considerations previously described. Thus for each of the four modulation types, one of four curves gives the bandwidth that can be supported at each distance value from 0 to 50 miles. If other availability percentages or other power levels were of interest, a similar set of curves could be generated. In fact, a complete set of studies for various combinations of availability percentages and power levels has been prepared and is attached to these comments.<sup>4</sup> Just to study four different availability percentages and the four modulation types and densities at a single power level takes a total of sixteen such curves.

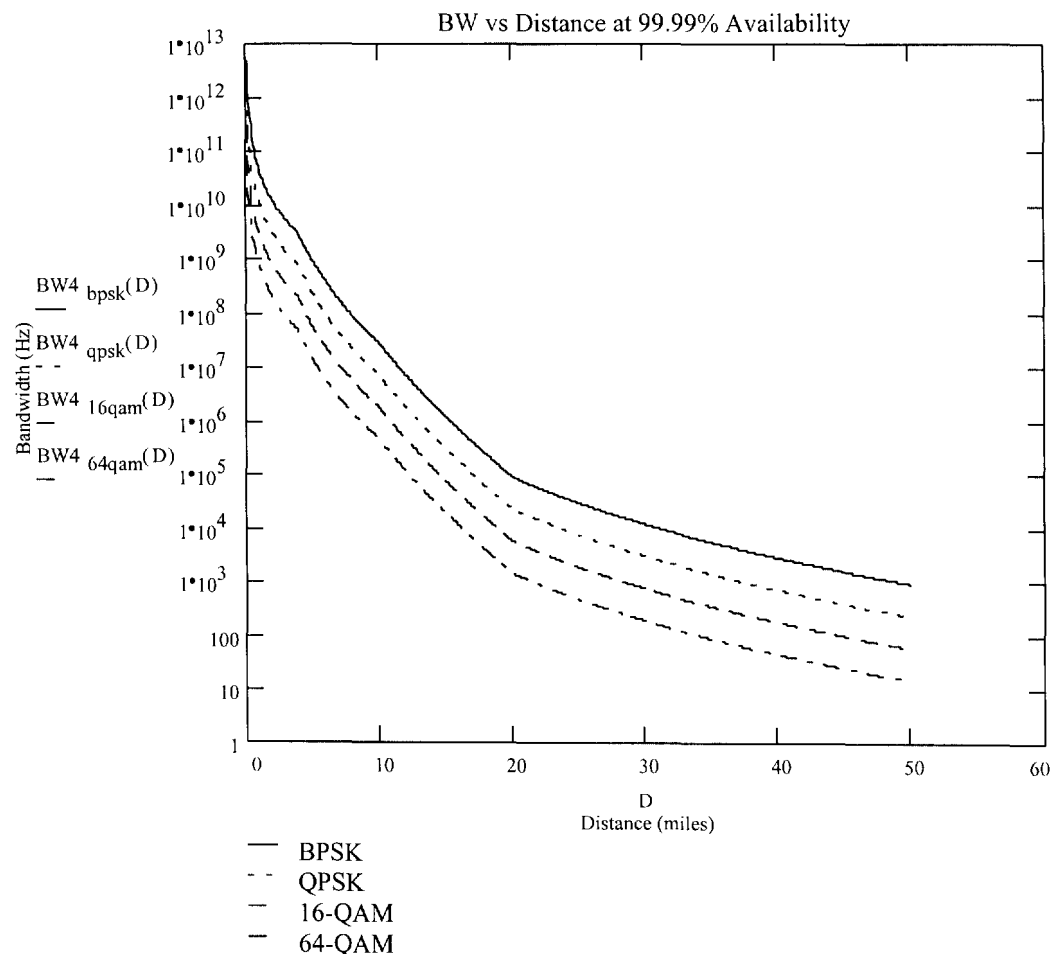


Figure 2 – Bandwidth vs. distance at +18 dBW EIRP

<sup>4</sup> See Attachment 1, "Analysis of Response Station Range vs. Bandwidth & Power," prepared by S. Merrill Weiss, Merrill Weiss Group, which gives the development of the charts used in this discussion.

## Power Limitations for Response Station Transmitters: An Analysis

The many relationships between distance that can be covered, bandwidths of the subchannels, modulation types, and availability percentages are summarized in Table 2 for a fixed EIRP of +18 dBW. The table is divided into four quadrants, each one representing a different subchannel bandwidth of 100 kHz, 600 kHz, 1 MHz, and 6 MHz, as previously described. Within each quadrant, the four modulation types and densities are listed across the top of the quadrant, and the four availability percentages of 99, 99.9, 99.99, and 99.999 percent are listed down the side. The data indicate the distance in miles that each specified signal will travel while achieving the given availability. Thus it can be seen, for example, that a 1 MHz bandwidth, 16-QAM signal transmitted at +18 dBW will yield 99.99 percent availability (corresponding to 53 minutes of annual outage) at a distance of 10.823 miles.

**Table 2 — Distance in Miles for 4 Subchannel Bandwidths, 4 Modulation Types, & 4 Availability Values at +18 dBW EIRP**

100 kHz	BPSK	QPSK	16-QAM	64-QAM	1 MHz	BPSK	QPSK	16-QAM	64-QAM
99%	49.065	37.22	28.235	21.417	99%	30.96	23.485	18.814	15.17
99.9%	30.96	23.485	18.814	16.142	99.9%	19.755	17.007	14.488	12.208
99.99%	19.755	17.007	14.488	12.208	99.99%	15.302	12.941	10.823	8.527
99.999%	15.302	12.941	10.823	8.527	99.999%	11.502	9.349	7.092	5.38
600 kHz	BPSK	QPSK	16-QAM	64-QAM	6 MHz	BPSK	QPSK	16-QAM	64-QAM
99%	34.29	26.012	19.86	16.604	99%	21.636	17.935	14.053	10.546
99.9%	21.636	17.998	15.393	13.023	99.9%	16.235	13.786	11.578	9.444
99.99%	16.235	13.786	11.578	9.444	99.99%	12.287	10.241	7.855	5.959
99.999%	12.287	10.241	7.855	5.959	99.999%	8.613	6.534	4.956	3.76

Looked at another way, the data in Table 2 can be used to determine the maximum service that can be delivered over various distances. For example, in the fairly common situation of a rural system that will use a single response station hub, probably sectorized, it will be desired to transmit back to the hub from the boundaries of the 35-mile protected service area (PSA). It can readily be seen that, with +18 dBW EIRP, this sort of distance can only be achieved with 99 percent availability at a maximum bit rate of 140 kb/s if 100 kHz bandwidth is used and at a maximum bit rate of 420 kb/s if 600 kHz bandwidth is used. Either way, higher bit rates cannot be achieved, and outages of 88 hours per year can be expected. This is not particularly reliable service and likely to be unacceptable for most applications.

Considering another likely common situation, suppose it is necessary to deliver the maximum bit rate possible, on the order of 25-27 Mb/s, in a cellularized system having 10 mile radius cells, with a reliability of 99.99 percent. Such a combination of parameters would be needed to serve a commercial or institutional subscriber at the edge of cell in system having a moderate number of cells. The required bit rate would necessitate use of 64-QAM modulation and a bandwidth of 6 MHz. Table 2 shows that this combination cannot be achieved with +18 dBW; either bandwidth would have to be limited to 8.4 Mb/s, the reliability would have to be limited to about 99.5 percent (approximately 44 annual hours of outage), or the cell would have to be limited in size to about six miles radius, requiring almost four times as many cells to cover a given area. These are all rather significant constraints on system performance.

Under the Commission's proposal, use of higher powers than +18 dBW EIRP for response stations would be allowed, but any installations which would exceed that value would require a separate application, followed by evaluation and authorization by the FCC. Given the very lengthy backlogs that are common in the Commission's review of MDS and ITFS applications, generally measured in years, this provision

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would make the use of any power levels higher than +18 dBW completely impractical from a business and competitive point of view. Not only would the burden of filing the many likely applications and keeping track of them be onerous for operators, but potential customers would not wait that long for service and clearly would seek other sources to meet their needs. This is not an acceptable result.

### Proposed alternative power limitations

An alternative proposal is the application of a limit of +33 dBW EIRP (+63 dBm) with an associated limit of +3 dBW (+33 dBm, or 2 Watts) on average transmitter output power. This proposal would permit maximum EIRP levels to reach a more realistic value for the types of applications contemplated for the proposed new service without placing the processing constraints on the service that have the potential to kill its commercial viability. It would also be in keeping with the Commission's recent decision in the Wireless Communications Service Reconsideration Order to permit maximum power levels of +33 dBW EIRP without specific authorization of each transmitter.

At the same time, this proposal would ensure that, as the power level is increased, interference would be reduced through the implied requirement that higher performance antennas be used to achieve the higher EIRP levels. Obtaining a power level of +33 dBW, for example, would require use of a 30 dB gain antenna (assuming no cable losses), something on the order of a six-foot diameter dish, significantly reducing the energy radiated in all directions other than in the main beam. A 24 dB gain antenna, a fairly common type in wireless cable use and much more easily implemented than a 30 dB gain antenna, would result in a maximum of +27 dBW EIRP (again, assuming no cable losses). While applications for authorization of response station hubs would still require the specification of the worst case antenna pattern for each class of response station and interference studies would have to be performed using those patterns, the current proposal would have the effect of forcing the use of significantly tighter antenna patterns on classes of response stations that are authorized for higher power levels, thereby further minimizing potential interference.

**Table 3 — Distance (miles) vs. Availability for 4 Subchannel Bandwidths & 4 Modulation Types at +33 dBW EIRP**

100 kHz	BPSK	QPSK	16-QAM	64-QAM	1 MHz	BPSK	QPSK	16-QAM	64-QAM
99%	97.9	74.26	56.335	42.735	99%	61.77	46.855	35.545	26.965
99.9%	61.77	46.855	35.545	26.965	99.9%	38.975	29.565	22.427	18.353
99.99%	38.975	29.565	22.427	18.353	99.99%	24.59	19.282	16.571	14.091
99.999%	24.59	19.282	16.571	14.091	99.999%	17.45	14.892	12.571	10.493
600 kHz	BPSK	QPSK	16-QAM	64-QAM	6 MHz	BPSK	QPSK	16-QAM	64-QAM
99%	68.418	51.9	39.37	29.865	99%	43.169	32.747	24.841	19.385
99.9%	43.169	32.747	24.841	19.385	99.9%	27.237	20.662	17.547	14.981
99.99%	27.237	20.662	17.547	14.981	99.99%	18.454	15.811	13.401	11.233
99.999%	18.454	15.811	13.401	11.233	99.999%	14.178	11.929	9.889	7.502

The impact of the use of a +33 dBW limitation on EIRP can be seen in Figure 3, which duplicates Figure 2 in all respects except the power level. Considering again the cases described when examining the impact of a +18 dBW EIRP limitation but now with a +33 dBW limitation, the single response station hub serving

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the edge of a 35-mile PSA would be able to achieve better than 99.99 percent availability (i.e., less than 53 minutes annual outage) at a bit rate of 70 kb/s in 100 kHz subchannel bandwidth, or about 99.95 percent availability (4.4 hours annual outage) at a bit rate of 420 kb/s in a 600 kHz bandwidth. In the case of the 10-mile radius cells needing to deliver 25-27 Mb/s, a bit better than 99.99 percent availability can be obtained using 64-QAM in a 6 MHz bandwidth. Thus the system objectives for viable services having reasonable reliability for commercial and institutional service can be routinely delivered in a timely manner, permitting the operations providing them to be competitive in the marketplace. At the same time, the Commission can be assured that, through the newly proposed limitations on transmitter output power and EIRP in combination with the previously proposed interference analysis regime, interference to neighboring systems will be minimized.

## Analysis of Response Station Range vs. Bandwidth & Power

Prepared by S. Merrill Weiss  
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This analysis considers various effects that will determine the realistic operating range of wireless cable response stations under the power limitations proposed by the FCC in its Notice of Proposed Rulemaking on MMDS and ITFS Fixed Two-Way Transmissions and under an alternative set of power limitations being proposed to the Commission. It shows what performance can be expected within the constraints imposed by the +18 dBW EIRP power limitation proposed by the Commission for response station transmitters operated under the blanket authority that will be associated with the authorization of response station hubs, and it shows the corresponding performance that can be obtained with the proposed alternative EIRP limit of +33 dBW.

To show what can be done within the confines of the two proposed power limits, the range from 0 to 50 miles is studied. Results are expressed in a series of graphs that relate the bandwidth that can be transmitted to the distance covered using different types of modulation and achieving various levels of signal availability. The analysis begins by determining the fade margin required over the range of distances studied in order to achieve four different levels of availability: 99%, 99.9%, 99.99%, and 99.999%, corresponding to annual outages of 88 hours, 8.8 hours, 53 minutes, and 5.3 minutes, respectively. Fade margin calculations are based upon the methods of Vigants and Barnett, as published in several sources. A chart is provided showing the fade margin required over the studied range for each value of availability.

Next, the path loss values are developed that will be used later in calculating performance. Path losses include free space path loss, excess path loss, and fade margin as determined previously. Free space path loss is determined over the distance range using a widely published method. Excess path loss is calculated based on the experience of Hardin & Associates, as related by George Harter, and represents knowledge gained from working with literally hundreds of installations around the world. These path losses are added together and combined with the four sets of values for fade margin to generate four sets of values for total path losses.

A mathematical model of the overall system is then developed from transmitting antenna output to receiver input. The model begins with the EIRP of the response station, converts it from dBW to dBm, adds the total path losses, adds losses for noise figure and transmission line at the receiver, adds gain for the receiving antenna, and determines the noise in a given bandwidth so that the carrier-to-noise ratio (C/N) can be calculated. The model is then solved for bandwidth, with the carrier-to-noise ratios required by different modulation types used as input parameters. The equation yielding bandwidth as the output parameter is then used for all remaining calculations.

The bandwidth equation is solved 16 times for each power level. The inputs represent a 4x4 matrix of the four availability percentages discussed previously and four modulation types: BPSK, QPSK, 16-QAM, and 64-QAM. The required C/N values for the four modulation types are set at 6 dB, 12 dB, 18 dB, and 24 dB, respectively.

The output of the analysis is a series of four graphs for each power level. Each presents one availability value and the four modulation types, with deliverable bandwidth shown versus distance for each type of modulation. Thus four graphs carry the sixteen cases that were analyzed for each power level. The first set of four graphs (Figures 9-12) carries the analysis of +18 dBW EIRP operation, while the second set (Figures 13-16) carries the analysis of +33 dBW EIRP operation.

The results of this analysis can be summarized in the statement that only limited performance relative to the objectives for the service can be achieved using the FCC's proposed +18 dBW EIRP limit on power levels for response stations operating under blanket authorizations. It is also clear from this study that the proposed alternative limitation to +33 dBW EIRP yields a much better range of possible service offerings, although it is still incapable of providing full-channel bandwidth delivery of the most complex, highest density modulation types to the outer reaches of a 35-mile PSA with the desired level of availability (99.99%).

## Fade Margin vs. Distance Calculated by the Method of Vigants & Barnett

a = 1 4 = very smooth terrain including overwater, 1 = average terrain with some roughness,  
1/4 = mountainous, very rough, or very dry

b = 1/4 1/2 = hot & humid areas, 1/4 = normal interior temperate or northern, 1/8 = mountainous or very dry

f = 2.686 GHz Frequency

D = 0.1, 0.2.. 50 miles Distance from Transmitter to Receiver (range variable)

$U_{ndp} = a \cdot b \cdot 2.5 \cdot 10^{-6} \cdot f \cdot D^3 \cdot 10^{\frac{F}{10}}$   $U_{ndp}$  = Unavailability Probability in Non-Diversity situations, F = Fade Margin

Solve for Fade Margin (F)

$$4.3429448190325182765 \cdot \ln \left[ 400000 \cdot \frac{U_{ndp}}{a \cdot b \cdot (f \cdot D^3)} \right]$$

$U_{ndp2} = 0.01$  unavailability probability (non diversity) ( $U_{ndp} = 1 - \text{Availability}$ , Availability = 99%)

$$F_2(a, b, f, D, U_{ndp2}) = -4.3429448190325182765 \cdot \ln \left[ 400000 \cdot \frac{U_{ndp2}}{a \cdot b \cdot (f \cdot D^3)} \right]$$

$U_{ndp3} = 0.001$  unavailability probability (non diversity) ( $U_{ndp} = 1 - \text{Availability}$ , Availability = 99.9%)

$$F_3(a, b, f, D, U_{ndp3}) = -4.3429448190325182765 \cdot \ln \left[ 400000 \cdot \frac{U_{ndp3}}{a \cdot b \cdot (f \cdot D^3)} \right]$$

$U_{ndp4} = 0.0001$  unavailability probability (non diversity) ( $U_{ndp} = 1 - \text{Availability}$ , Availability = 99.99%)

$$F_4(a, b, f, D, U_{ndp4}) = -4.3429448190325182765 \cdot \ln \left[ 400000 \cdot \frac{U_{ndp4}}{a \cdot b \cdot (f \cdot D^3)} \right]$$

$U_{ndp5} = 0.00001$  unavailability probability (non diversity) ( $U_{ndp} = 1 - \text{Availability}$ , Availability = 99.999%)

$$F_5(a, b, f, D, U_{ndp5}) = -4.3429448190325182765 \cdot \ln \left[ 400000 \cdot \frac{U_{ndp5}}{a \cdot b \cdot (f \cdot D^3)} \right]$$

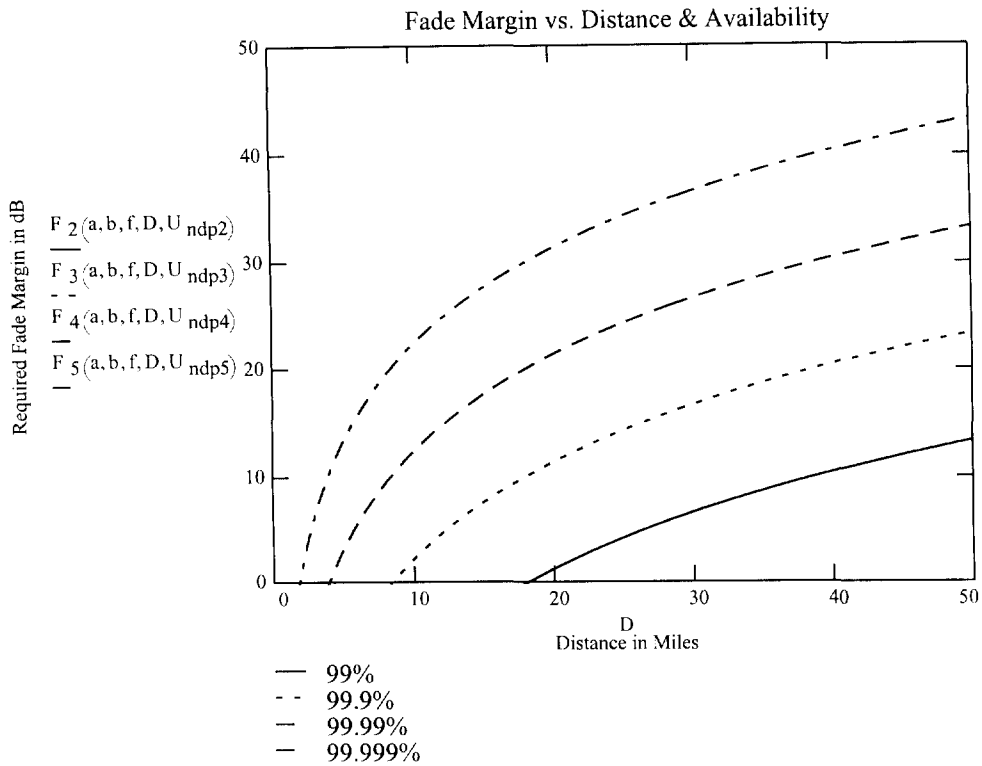


Figure 1 – Fade margin versus distance and availability for availability values of 99%, 99.9%, 99.99% and 99.999%

## Calculations of Path Losses

Freq = 2686 MHz

$$\alpha(\text{Freq}, D) = 36.6 + 20 \cdot \log(\text{Freq}) + 20 \cdot \log(D) \text{ Path Attenuation (FreeSpace) (dB)}$$

$$\varepsilon(D) = 10 + \text{if}((D > 10) \cdot (D < 20), D - 10, \text{if}(D < 10, 0, 10)) \text{ Excess Path Loss (dB)}$$

$$\rho(D) = \alpha(\text{Freq}, D) + \varepsilon(D) \text{ Attenuation + ExcessPL (dB)}$$

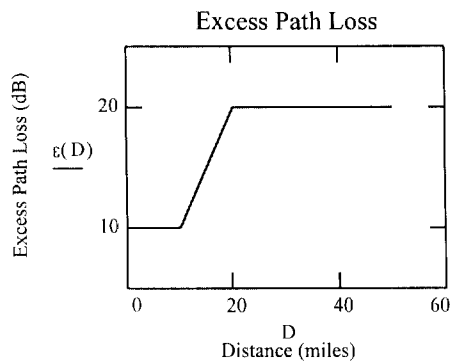


Figure 2 – Excess path loss

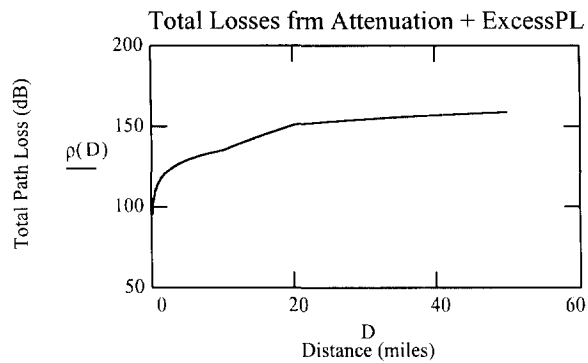


Figure 3 – Total losses from free space attenuation and excess path loss

## Total Path Losses

$$\tau_2(D) = \rho(D) + \text{if}(F_2(a, b, f, D, U_{\text{ndp}2}) > 0, F_2(a, b, f, D, U_{\text{ndp}2}), 0) \text{ Total Path Losses (99\%)}$$

$$\tau_3(D) = \rho(D) + \text{if}(F_3(a, b, f, D, U_{\text{ndp}3}) > 0, F_3(a, b, f, D, U_{\text{ndp}3}), 0) \text{ Total Path Losses (99.9\%)}$$

$$\tau_4(D) = \rho(D) + \text{if}(F_4(a, b, f, D, U_{\text{ndp}4}) > 0, F_4(a, b, f, D, U_{\text{ndp}4}), 0) \text{ Total Path Losses (99.99\%)}$$

$$\tau_5(D) = \rho(D) + \text{if}(F_5(a, b, f, D, U_{\text{ndp}5}) > 0, F_5(a, b, f, D, U_{\text{ndp}5}), 0) \text{ Total Path Losses (99.999\%)}$$

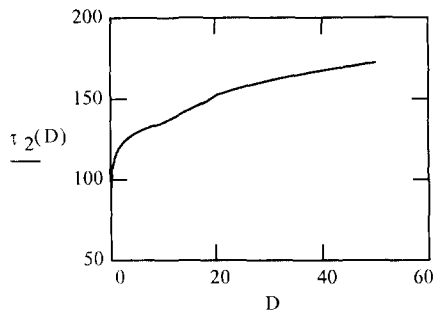


Figure 4 – Total path losses at 99% availability

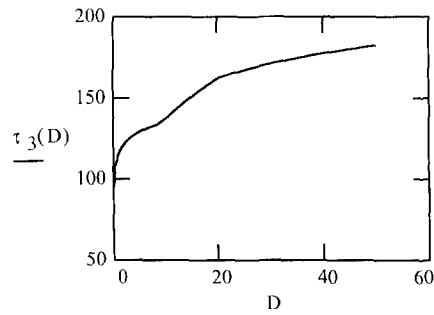


Figure 5 – Total path losses at 99.9% availability

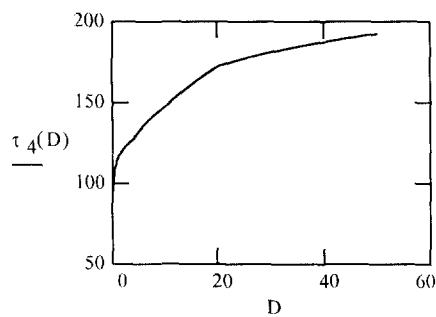


Figure 6 – Total path losses at 99.99% availability

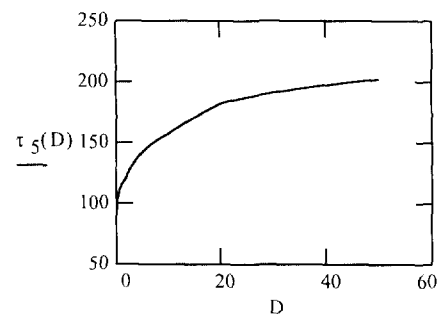


Figure 7 – Total path losses at 99.999% availability

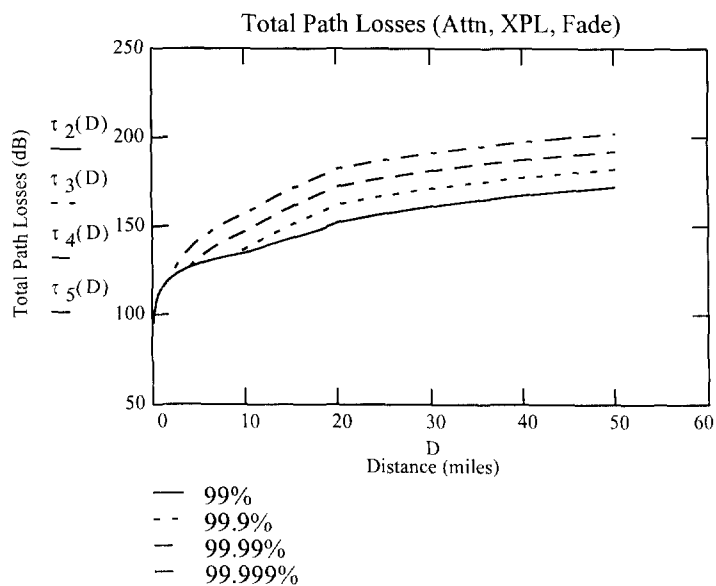


Figure 8 – Total path losses for all four availability values

## Mathematical System Model

### Noise vs. Bandwidth Calculations

T = 63 degrees Fahrenheit

bw =  $5 \cdot 10^6$  MHz

k =  $1.380662 \cdot 10^{-23}$  Boltzmann constant

P<sub>ref</sub> = 0.001 Watts

$$P_{\text{noise}} = 10 \cdot \log \left[ k \cdot \left( \frac{5}{9} \cdot (T - 32) + 273 \right) \cdot \frac{\text{bw}}{P_{\text{ref}}} \right]$$

$$P_{\text{noise}} = 106.982 \text{ dBm}$$

### Miscellaneous Input Parameters

P<sub>t</sub> = 18 Transmitter Power (EIRP)(dBW)

G<sub>r</sub> = 10 Receiving Antenna Gain (dB)

TL = 2 Transmission Line Loss (dB)

NF = 2 Noise Figure (dB)

CN<sub>bpsk</sub> = 6 (dB)

CN<sub>qpsk</sub> = 12 (dB)

CN<sub>16qam</sub> = 18 (dB)

CN<sub>64qam</sub> = 24 (dB)

### Model with Fixed Bandwidth and Carrier-to-Noise as Range Variable

$$\text{CN}(D) = P_t - 30 - \tau_2(D) - TL + G_r - NF - 10 \cdot \log \left[ k \cdot \left( \frac{5}{9} \cdot (T - 32) + 273 \right) \cdot \frac{\text{BW}}{P_{\text{ref}}} \right]$$

### Solve for Bandwidth (Carrier-to-Noise is still a range variable)

$$\exp \left( \frac{1}{10} \cdot \text{CN}(D) \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10) \right) \cdot \left( \frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}} \right)$$

## Bandwidth vs. Distance at 99% Availability & +18 dBW EIRP

$$BW2_{\text{bpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{bpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) - \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW2_{\text{qpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{qpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) - \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW2_{16\text{qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{16\text{qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) - \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW2_{64\text{qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{64\text{qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) - \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

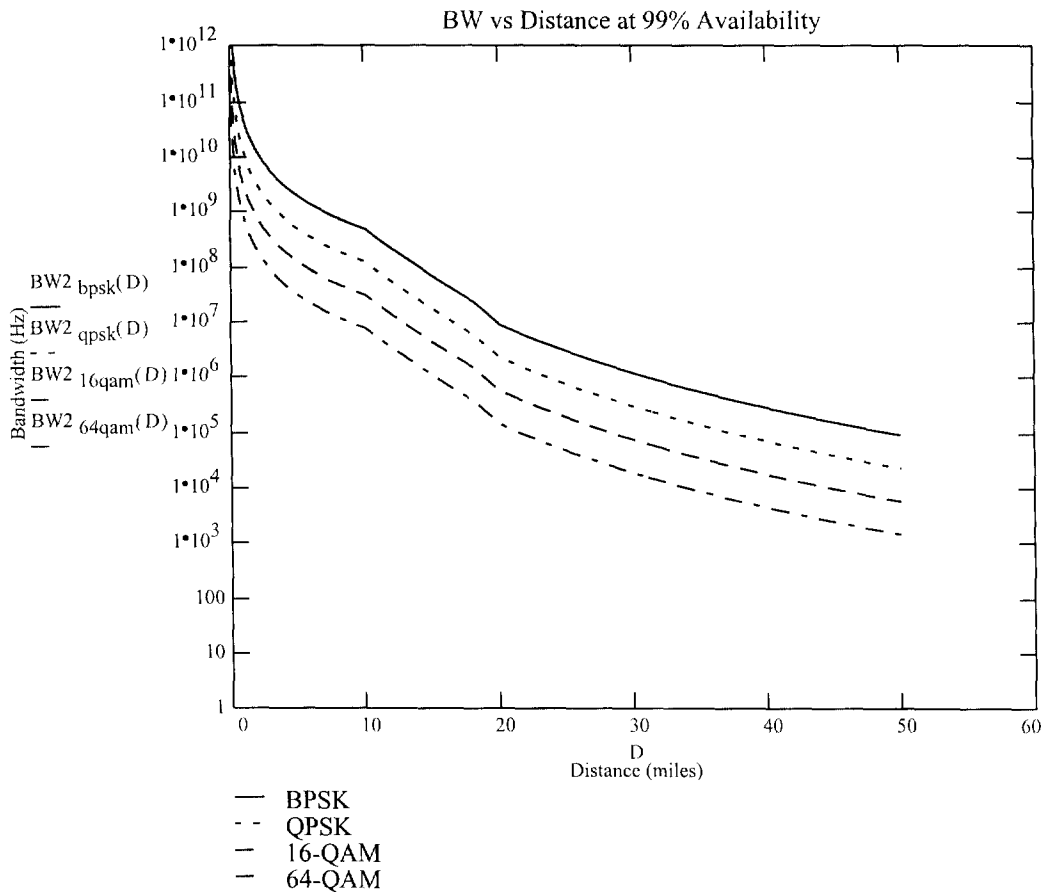


Figure 9 – Bandwidth versus distance at 99% availability & +18 dBW EIRP

## Bandwidth vs. Distance at 99.9% Availability & +18 dBW EIRP

$$BW3_{bpsk}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{bpsk} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_3(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{ref}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{ref}}\right)}$$

$$BW3_{qpsk}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{qpsk} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_3(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{ref}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{ref}}\right)}$$

$$BW3_{16qam}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{16qam} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_3(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{ref}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{ref}}\right)}$$

$$BW3_{64qam}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{64qam} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_3(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{ref}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{ref}}\right)}$$

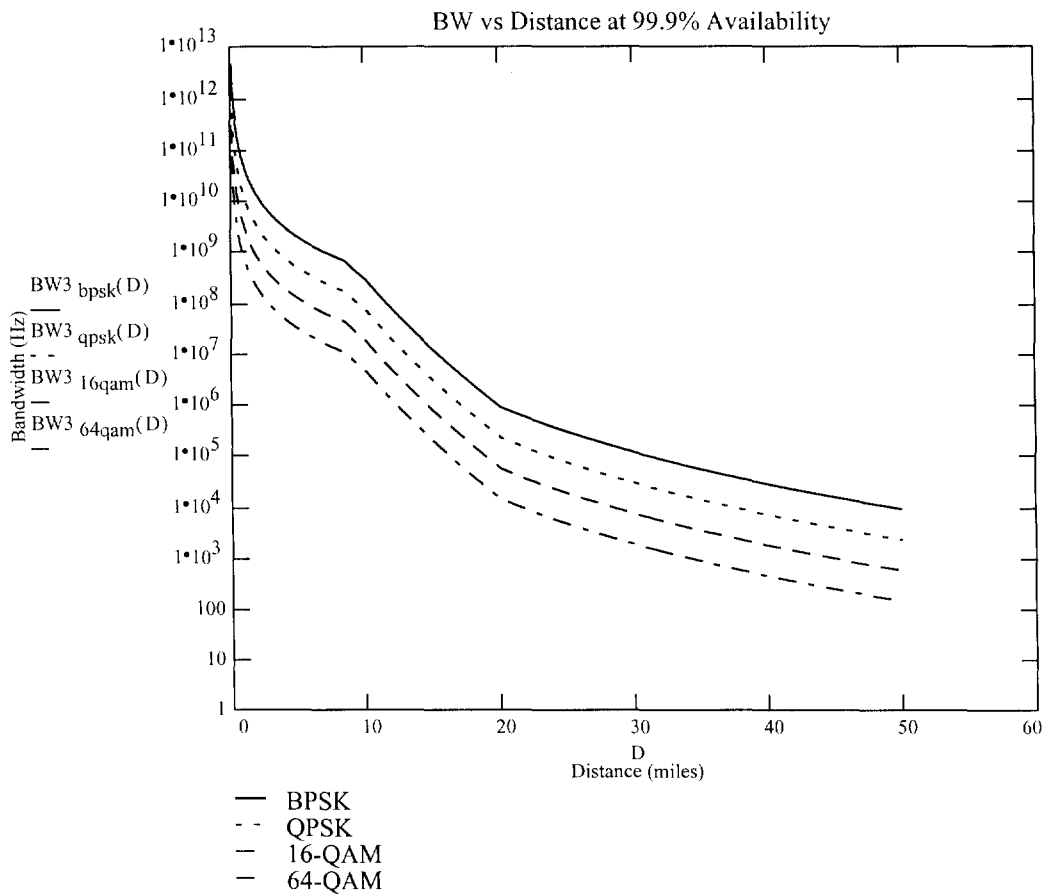


Figure 10 – Bandwidth versus distance at 99.9% availability & +18 dBW EIRP

## Bandwidth vs. Distance at 99.99% Availability & +18 dBW EIRP

$$BW_{4 \text{ bpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{bpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_4(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{4 \text{ qpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{qpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_4(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{4 \text{ 16qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{16qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_4(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{4 \text{ 64qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{64qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_4(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

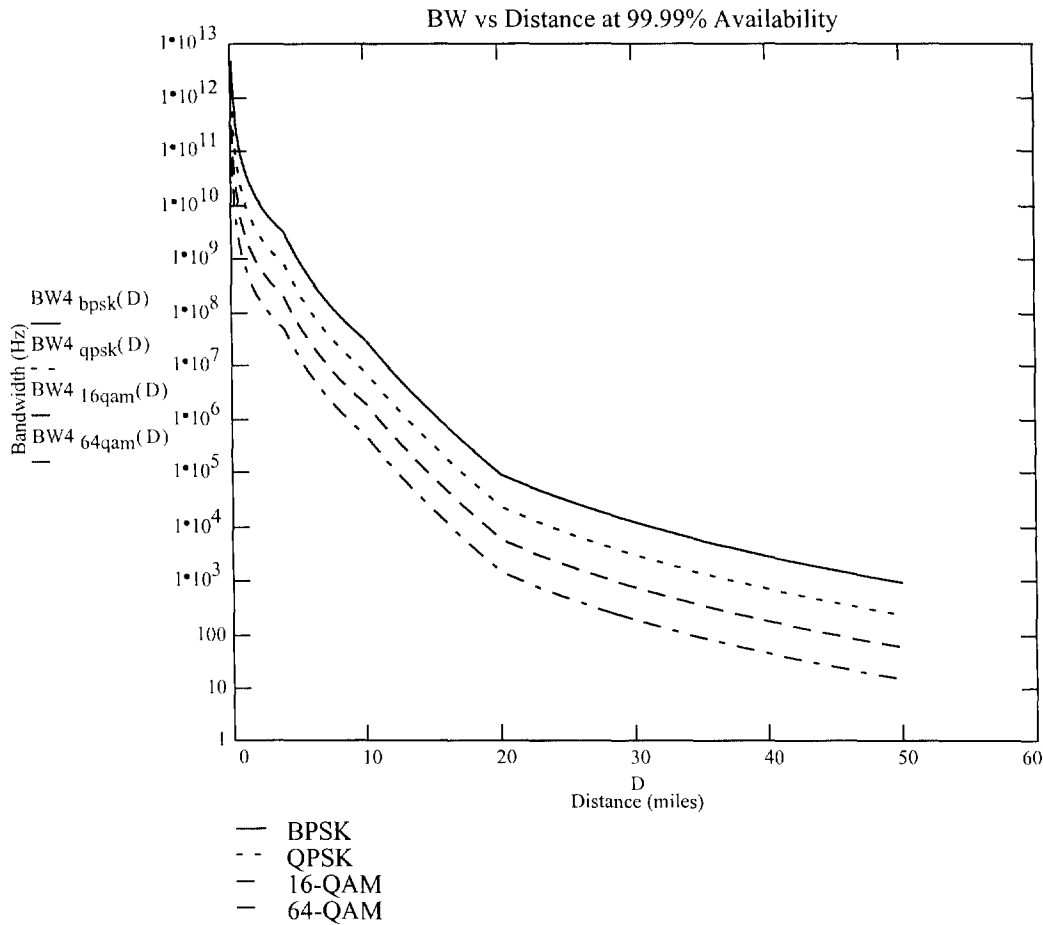


Figure 11 – Bandwidth versus distance at 99.99% availability & +18 dBW EIRP

## Bandwidth vs. Distance at 99.999% Availability & +18 dBW EIRP

$$\begin{aligned}
 BW5_{\text{bpsk}}(D) &= \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{bpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_5(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)} \\
 BW5_{\text{qpsk}}(D) &= \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{qpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_5(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)} \\
 BW5_{16\text{qam}}(D) &= \frac{\exp\left(\frac{1}{10} \cdot CN_{16\text{qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_5(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)} \\
 BW5_{64\text{qam}}(D) &= \frac{\exp\left(\frac{1}{10} \cdot CN_{64\text{qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_5(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}
 \end{aligned}$$

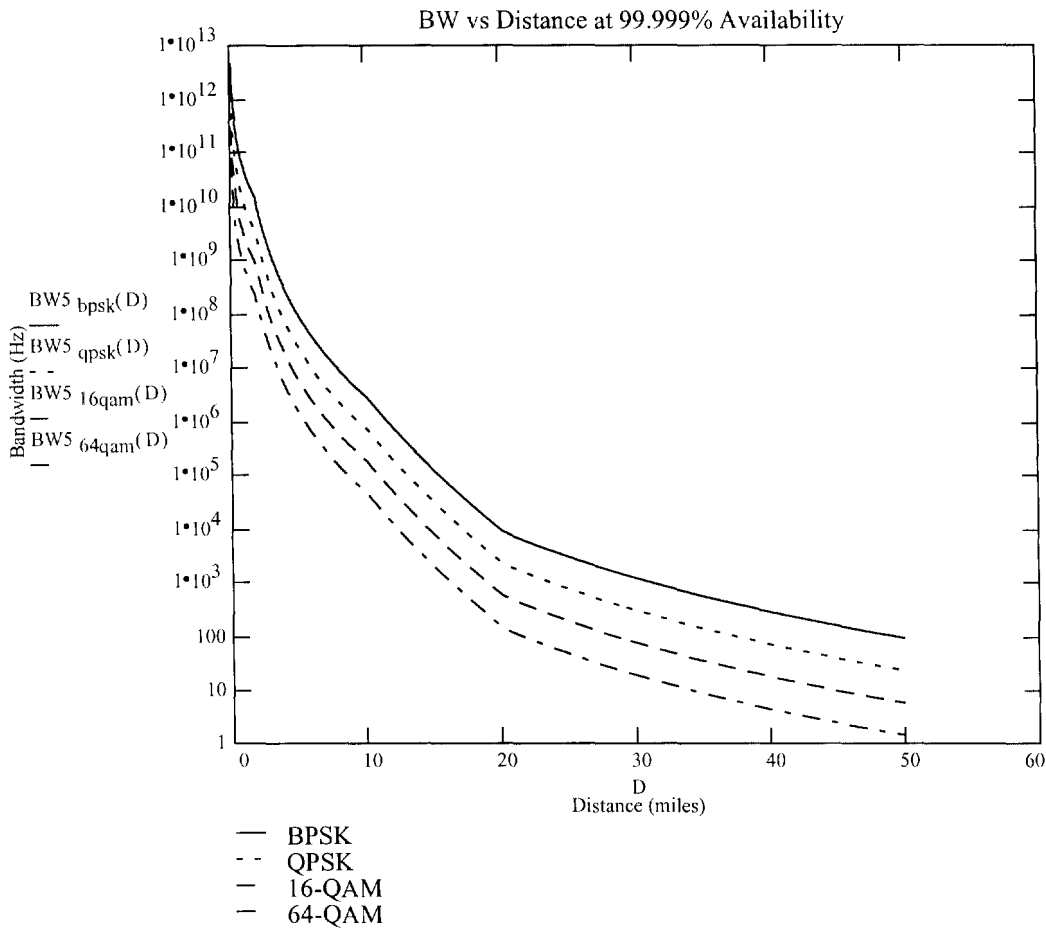


Figure 12 – Bandwidth versus distance at 99.999% availability & +18 dBW EIRP

# **Bandwidth vs. Distance at 99% Availability & +33 dBW EIRP**

$P_t = 33$  Transmitter Power (EIRP)(dBW)

$$BW_{2 \text{ bpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{bpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{2 \text{ qpsk}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{qpsk}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{2 \text{ 16qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{16qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

$$BW_{2 \text{ 64qam}}(D) = \frac{\exp\left(\frac{1}{10} \cdot CN_{\text{64qam}} \cdot \ln(10) + \frac{1}{10} \cdot P_t \cdot \ln(10) + 3 \cdot \ln(10) - \frac{1}{10} \cdot \tau_2(D) \cdot \ln(10) - \frac{1}{10} \cdot TL \cdot \ln(10) + \frac{1}{10} \cdot G_r \cdot \ln(10) - \frac{1}{10} \cdot NF \cdot \ln(10)\right)}{\left(\frac{5}{9} \cdot \frac{k}{P_{\text{ref}}} \cdot T - \frac{2297}{9} \cdot \frac{k}{P_{\text{ref}}}\right)}$$

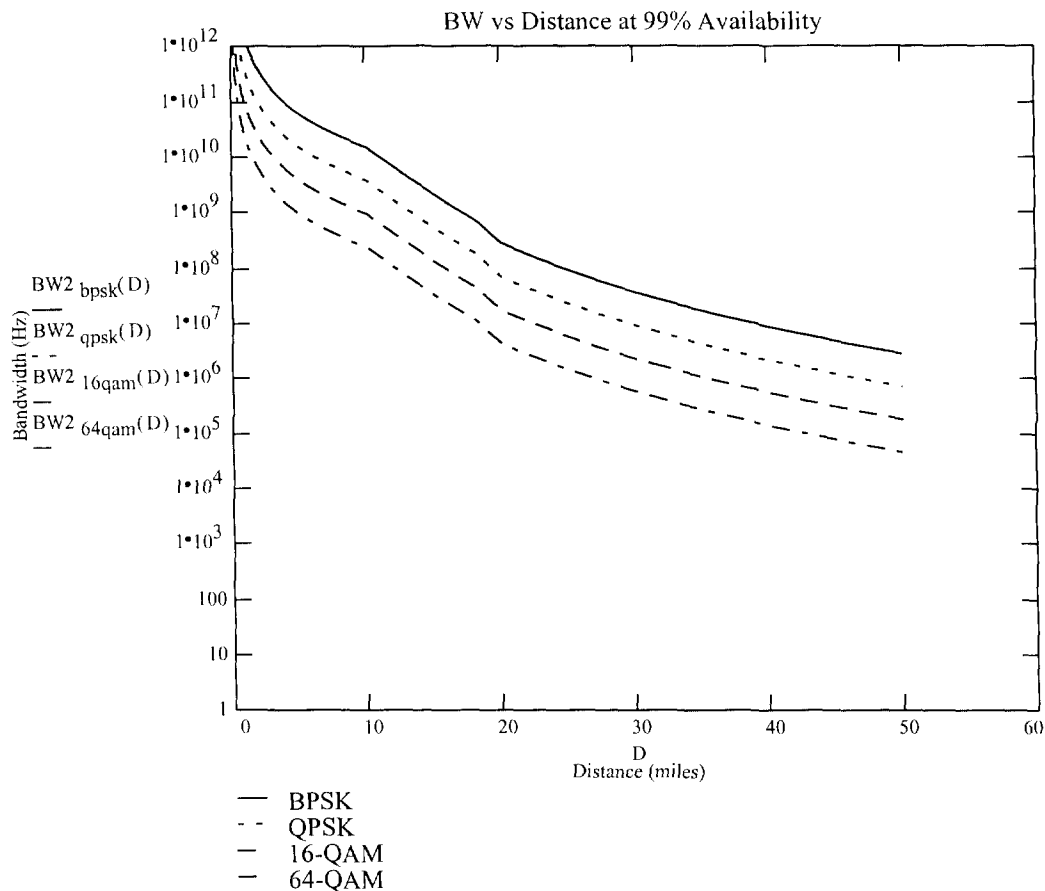


Figure 13 – Bandwidth versus distance at 99% availability & +33 dBW EIRP